

CONSTELLATION X-RAY MISSION AND SUPPORT

NASA Cooperative Agreement NCC5-368

Fifth Annual Report

For the Period October 1, 2002 to September 30, 2003

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1.0 Introduction

This Fifth Annual Report summarizes work performed by the Smithsonian Astrophysical Observatory (SAO) for NASA Goddard Space Flight Center (GSFC) under Cooperative Agreement NCC5-368¹. The Agreement is entitled "Constellation X-ray Mission Study and Support." This report covers the period from October 1, 2002 through September 30, 2003.

SAO continues to perform work under the overall direction of Dr. Harvey Tananbaum, the SAO Principal Investigator for the program. Mr. Robert Rasche is the SAO Program Manager and is responsible for day-to-day program management at SAO and for management coordination with GSFC.

The report summarizes the main areas of SAO activity. Most of the work has been done jointly with personnel from GSFC and Marshall Space Flight Center (MSFC). We describe SAO participation in these efforts.

As is appropriate to a Cooperative Agreement, SAO continued to work with GSFC in an integrated team mode. SAO was involved in the overall mission management, technology development, scientific direction, and mission definition. While formal overall management responsibility resides with GSFC, scientific lead and subordinate responsibilities continue to be shared by GSFC and SAO.

The work performed by SAO is consistent with the SAO proposal "Constellation X-ray Mission Study and Optics Development" dated September 1997, which was the basis for establishing the subsequent Cooperative Agreement. Over time, the scope of the effort has expanded somewhat to accommodate the needs of the project. Work, except for meeting support and high priority program tasks, has been at a level of effort.

During the reporting period, the Project at GSFC began to reorganize. After the TRIP report effort, Ms. Elizabeth Citrin, was appointed Project Manager. The previous Project Formulation Manager, Jean Grady, became the Deputy Project Manager.

Priorities and work progress continued to be closely coordinated with the Constellation-X Project management at GSFC. As usual, funding limitations constrained the work accomplished during this period.

Regrettably, Dr. Leon Van Speybroeck died in December 2002, leaving us without his incisive and objective review and guidance. Dr. Paul Reid who led the Chandra mirror fabrication and assembly work for what was then Hughes Danbury and who is a recognized expert in his own right joined SAO in June 2003. Dr. Reid's primary assignment is to the Constellation-X program at SAO.

In spite of the work being mainly a level of effort, a significant amount of work was accomplished. Under the Agreement, SAO performed work in eight major areas of activity. These areas related to:

- Constellation X-ray Mission Facility Definition Team and Study Management
- Science Support

¹ In subsequent text, NCC5-368 is simply referred to as the "Agreement". A Cooperative Agreement is the appropriate vehicle for the close, flexible, and wide ranging interaction between SAO and NASA needed to ensure the success of the Constellation-X project formulation activity.

- Spectroscopy X-ray Telescope (SXT)
- Systems Engineering
- Travel in Support of the Work Effort
- In-house Management and Coordination
- TRIP Report and Follow-up
- Industry Liaison and Study Preparation

The following sections summarize work performed by SAO during the reporting period.

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2.0 Constellation X-ray Mission Definition Team and Study Management

2.1 General Study Management and Coordination

SAO continued to be heavily involved in Constellation-X mission definition and the overall management of the study. Management decisions continued to involve the Project Scientist, Dr. Nicholas White (GSFC), the Facility Science Team Chairman, Dr. Harvey Tananbaum (SAO)², the Project Manager Ms. Elizabeth Citrin (GSFC), the Deputy Project Manager, Ms. Jean Grady (GSFC), and the SAO Program Manager, Mr. Robert Rasche. Frequently the two Mission scientists, Dr. Jay Bookbinder (SAO) and Dr. Robert Petre (GSFC) were also involved. Dr. White is frequently assisted or represented by the Deputy Project Scientist, Dr. Kimberly Weaver of GSFC.

SAO was a major participant in the technical overview, planning, and review of both future work and work in progress with particular emphasis on the SXT Mirror Assembly and its related Optical Assembly Pathfinder, Engineering Unit, and Prototype assemblies.

SAO continued to be involved in the management of mission definition activities, particularly with regard to thermal control, error budget development, and developing both science and top level mission requirements as well as the many related flow-down requirements. SAO personnel brought extensive and relevant experience from CHANDRA, HEAO, TRACE, HST, and other programs to the Constellation-X mission definition work.

Drs. White and Tananbaum had primary responsibility for scientific management with support from Drs. Bookbinder (SAO), Weaver (GSFC), and Petre (GSFC) and, occasionally, others. This included coordination with members of the Facility Science Team, interactions with NASA Headquarters and the scientific community at large, as well as participation in the Constellation-X Study Team meetings that were held approximately every two weeks at GSFC. Other special meetings were also supported.

The SAO management team participated aggressively in establishing plans, budgets, presentations, and priorities. This has been and continues to be an on-going and more or less continuous activity. A major planning effort was required to develop the TRIP report (see Section 8.0)

2.2 Technology Development Management and Coordination

Under the Agreement, SAO has an important role in managing and coordinating technology development for Constellation-X. That role continued through the reporting period. Mr. Rasche was involved in coordinating technology development. He was supported by other SAO staff and, of course, worked closely with both GSFC and MSFC staff.

SAO's main technology management involvement has been related to the SXT X-ray mirror and the reflective gratings. However, SAO has also kept involved with and informed of instrument technology developments and related planning and budget negotiation. Since the IPT funding comes through GSFC contracts, the SAO role has been primarily to provide expertise, coordination, and general overview to the instrument development work. SAO supported most project teleconferences related to instrument and mirror technology.

² Because Constellation-X is a consolidation of their individually proposed and accepted programs into a single program, Drs. White and Tananbaum function as equal Co-Principal Investigators although they have well-defined and separate formal responsibilities.

During the reporting period, meetings were held between SAO and Dr. Webster Cash (U of Colorado) to discuss both technical and programmatic issues related to the "off-plane" grating concept. SAO began to be more heavily involved in monitoring and evaluating progress being made in "off plane" grating technology. That activity continues today.

2.3 Reports and Presentations

SAO personnel developed and made presentations at many meetings. These meetings included the biweekly team meetings at GSFC, and related splinter meetings, as well as technical interchange meetings (TIMs). The TIMs have generally been related to work on the SXT Optical Assembly Pathfinder. SAO (Podgorski and/or Reid) make presentations at the monthly SXT Mirror Status Meetings.

2.4 Mission Studies

SAO personnel also made direct technical contributions to the ongoing mission studies at GSFC and to discussions and trades related to mission operations and instrument accommodation. This helped ensure that relevant CHANDRA (AXAF) experience (which is ongoing) in these areas was transferred to the Constellation-X program in an effective and continuous way. These contributions have tended to be related to systems engineering issues -- an SAO strength (see Section 5).

2.5 Coordination with Industry (see also Section 9.0)

SAO staff were involved in a number of project management interactions between the Constellation-X project and industry. These interactions were both formal and informal. The objective has been two-fold:

- To help industry maintain a continued awareness of relevant technologies and interests.
- To encourage interest in the Constellation-X project on the part of industry.
- To establish useful IR&D programs of benefit to Constellation-X.
- To ensure that industry concerns were represented in project planning.

3.0 Science Support

3.1 Chair of the Facility Science Team (FST)

Under the Agreement, SAO provided the Chair of the Constellation-X Facility Science Team, the group of scientists who help guide the program with regard to scientific objectives and needed capabilities. Dr. Tananbaum serves as Chair and is assisted by the Mission Scientist, Dr. Bookbinder and other members of the FST from several institutions and, of course, the Project Scientist, Dr. White and his science colleagues at GSFC.

During the period of performance, Dr. Tananbaum was a point of contact for both general FST members as well as for the leaders of the instrument technology teams. This activity was closely coordinated with Dr. White at GSFC who carried out a similar function. In general, Dr. White was more involved with the Government members of the FST and Dr. Tananbaum worked with FST members from non-Government organizations.

3.2 Mission Scientist

As required by the Agreement, SAO provided the expert services of Dr. Jay Bookbinder who filled the position of the Mission Scientist from SAO. His GSFC counterpart is Dr. Robert Petre.

Dr. Bookbinder participated in team meetings at GSFC and SAO and was an active and direct technical contributor to the SAO team. He also carried out special assignments for the FST Chair, Dr. Tananbaum. Dr. Bookbinder brought substantial and relevant expertise and experience from TRACE, the ongoing Solar-B, and other NASA programs. Working with others, he continued to further define and document the Constellation-X Top Level Requirements. A significant amount of both analysis and coordination with others was required to carry out this activity.

3.3 Representation at Various Scientific Meetings

Drs. Tananbaum and Bookbinder attended and participated in scientific and advisory committee meetings during the period. Their participation at these events helped to promote the Constellation-X program by providing information about the program, answering questions, and soliciting inputs to help ensure a balanced, effective, and significant science program.

3.4 Facility Science Team Meetings

Work during this reporting period involved close out of actions arising out of the September 2002 FST meeting and planning and carrying out an FST Meeting the was held at Columbia University during May 2003. SAO also participated in preliminary planning for an FST meeting at GSFC for Fall 2003.

4.0 Spectroscopy X-ray Telescope (SXT)

During the reporting period, more SAO effort was applied to the Spectroscopy X-ray Telescope and, in particular, to its X-ray mirror³ than to any other task. SAO performed SXT related work in six main areas:

1. SXT Management and Coordination
2. SXT Mirror Module Design
3. SXT Mirror Assembly and Alignment Studies
4. SXT Error Budget Development
5. Segment Mirror Mandrel Procurement
6. Flight Mirror Development Planning

4.1 SXT Management and Coordination

Working with the concurrence of the Project Management, SAO provided extensive oversight and direction to the Constellation-X SXT mirror definition and development. This activity included but was not limited to:

- Participation in numerous status review and planning teleconferences
- Informal tracking of SXT work progress at MSFC, GSFC, and SAO
- Evaluation and informal reporting of progress to GSFC Constellation-X project office.
- Development and evaluation of work plans and budgets
- Formulation and presentation of recommendations for future plans and priorities
- General overview of SXT work

4.2 SXT Mirror Module Design

SAO continued in-house concept and analysis studies related to SXT segmented mirror concepts, and, in particular, the OAP and the engineering and prototype units that will follow it. William Davis (SAO) has provided essentially all of the precision structural analysis support to the ongoing work. In this role, Davis worked closely with his GSFC counterparts and participated in telephone conferences and on site meetings at GSFC.

As work on the OAP and subsequent designs progressed, SAO tracked and helped to evaluate the technical progress. This overview provided independent assessments and recommendations to the GSFC Project Manager.

A low level effort was started to evaluate technologies other than epoxy replication. The basic notion is to form smooth glass and then machine the final figure into the substrate without

³ Technically the term Spectroscopy X-ray Telescope refers to the complete X-ray telescope. In practice, the term SXT and SXT Mirror have, unfortunately, come to be used interchangeably. The greater portion of SAO activity related to the SXT was directed at the X-ray mirrors per se.

excessive degradation to the surface finish. Such an approach, if feasible, might produce a reflector having better resolution than can probably be obtained using epoxy replication. In this context, both ion polishing (figuring) and MRF technology are being evaluated.

4.3 SXT Mirror Assembly and Alignment Studies

SAO, together with its subcontractor Bauer Associates, has become an integral part of the OAP mirror adjustment and evaluation work. Dr. Podgorski and Mr. Glenn work in a hands on way with GSFC and MSFC colleagues. This work has and continues to involve structural analysis support from Davis (SAO). SAO has built and is about to deliver a temperature controlled chamber for OAP test at MSFC.

A Constellation-X Centroid Detector Assembly (CDA) was started at Bauer. The CDA is a unique extension of technology developed on Chandra.

4.4 SXT Error Budget Development

Work on the SXT error budget continued during the reporting period although because of both personnel and funding conflicts, the effort was somewhat limited. Nonetheless, substantial progress was made. This was facilitated by the close working relationship that has now developed between Drs. Podgorski (SAO) and Dr. Saha (GSFC) who are both involved in the development of the error budget. They have tended to take different approaches which when their analyses produce equivalent results (they usually do) provides an important check on the work as a whole.

SAO also developed and is maintaining and enhancing an error budget for the OAP assemblies and related test set-ups.

4.5 Segmented Mirror Mandrel Procurement

SAO has participated in the overview of mandrel development work at Zeiss being carried out under a MSFC contract. SAO participates in monthly status meetings and reviews contract documentation. Two of three mandrels have been delivered to MSFC. The first mandrel is a particularly important milestone in that it is the mandrel having the largest radius of curvature and hence the largest arc length. SAO was also involved in the subsequent procurement planning for forming mandrels. Because of its close relation to flight mandrel planning, Rasche (SAO) has been most involved in this effort.

4.6 SXT Flight Mirror Program Planning

Useful SXT mirror technology will almost certainly be constrained by at least three factors related to flight mirror development rather than mirror technology per se. These factors are:

- Availability of required infrastructure and expertise
- Ability to obtain required infrastructure where none exists
- Corporate willingness to accept a contract for large flight or even prototype mandrels, particularly when compared with other business opportunities.

Working with Dr. Zhang and others at GSFC, Rasche (SAO) developed a reference approach to flight mandrel procurement as well as an excellent working relationship with Zeiss and, to a lesser degree with Schott. In December, Rasche met with representatives of both Schott and Zeiss to discuss flight program issues in considerable detail and to coordinate inputs for the TRIP

exercise (See Section 8). The visit was highly successful. Because much of the discussion was competition sensitive, it will not be reported here.

5.0 Systems Engineering

SAO continued to provide systems engineering support to the Constellation-X project. Work was concentrated in five main areas:

- Thermal control
- Requirements and requirements flow down development
- Opto-structural analysis of segmented SXT concepts
- System error budgets

5.1 Thermal Control

SAO and GSFC continued to work together in the areas of both instrument and overall system thermal control. In particular, Boyd and Freeman at SAO and Wes Ousley at GSFC continued to review the system as it developed and coordinated closely with each other. Effort by SAO in this area was limited primarily by available funding. SAO continued work related to SXT Mirror Assembly temperature control and has now developed power and temperature control envelopes as a function of thermal precollimator concepts. A parametric collimator study was completed and is now being applied to the Constellation-X application.

5.2 Requirements and Requirements Flowdown

The Constellation-X Top Level Requirements have been defined although a few of them may be modified. Recent work continues to focus on flow down requirements on the various Constellation-X subsystems. This work is being done primarily by Drs. Bookbinder and Podgorski with the participation and review of others as appropriate. This work included analysis and research related to establishing numerical values for the various requirements.

5.3 Opto-Structural Analysis of Segmented SXT Concepts

As indicated in Section 4.2 SAO provided optical and structural analysis support to the emerging SXT Engineering Unit effort. SAO also was somewhat involved and continues to be involved in the systems (and structural) engineering related to the Constellation-X gratings.

5.4 System Error Budgets

Some, but not much work was done during the reporting period to extend system error budgets. That more work was not done in this area was due mainly to funding limitations. This important activity will receive much more attention in the coming year, particularly those components associated SXT mirror assembly design concepts.

6.0 Travel

The Agreement provided funding for frequent program travel. Most, but certainly not all, of the travel was between SAO and either GSFC or MSFC.

With few exceptions, a Constellation-X Study Team meeting was held at GSFC every other week between 1:00 p.m. and 3:00 p.m. with splinter meetings on either side of this fixed time. This arrangement allowed SAO personnel to travel from Boston to GSFC and return on the same day with substantial savings in lodging and per diem costs. These meetings were usually attended by at least one SAO person and occasionally by three or four if required by either the meeting agenda or related splinter meetings. Whenever possible, splinter meetings were set up on the same day as the team meetings. These meetings were usually technical interchange meetings that took the form of informal working meetings. However, some of the splinter meetings were management review and planning meetings.

SAO staff working on SXT mirror technology traveled to GSFC and to MSFC. These trips related primarily to OAP alignment and test and to various technical interchange meetings.

Travel also included on-site discussions with Zeiss and Schott by Rasche (SAO) relative to planning inputs to the TRIP report.

7.0 In-House Management and Coordination

In addition to the direct participation in the Constellation-X project summarized above, SAO carried out housekeeping, coordination, and planning activities at SAO. This work related to the orderly operation of the SAO Constellation-X team.

These activities included:

- Cost planning, tracking, analysis, and control
- Time keeping
- Personnel evaluation inputs
- Purchasing and logistics
- Coordination and information meetings
- Travel arrangements

SAO did not produce any stand-alone formal documents as such during the period of performance. Analyses, error budgets, area vs. energy plots, and requirements were developed and documented as informal documents, particularly by Bookbinder, Cohen and Podgorski. These were distributed in a timely way as attachments to e-mail messages. The Constellation-X Top Level Requirements document and its companion Flow Down Requirements document are still in process and will, in any event, be released as project documents. Of course, the most significant document produced was the TRIP report.

8.0 TRIP Report

Beginning in November 2002 and extending into February 2003, SAO was heavily involved in an intense effort to respond to NASA Headquarters direction to prepare a Technical Readiness and Implementation Plan (TRIP) report which was, in effect, a combination Phase A study and proposal effort. Tananbaum, Bookbinder, Podgorski, and Rasche worked closely with key GSFC project personnel. Brissenden (SAO) chaired our red team.

The work involved extensive travel, long hours, and extremely close and real time coordination. SAO not only provided extensive inputs and plans, but also helped to coordinate, edit, and negotiate the inputs of others.

9.0 Industry Liaison and Study Planning

SAO participated in expanding liaison with key industrial organizations. This was facilitated by many long-term personal relationships extending from the Chandra program. Discussions related to possible IR&D efforts, industry concerns about the program schedule and funding, as well as to general interest and capabilities.

Industry inputs were explicitly solicited for both the spacecraft and SXT aspects of the TRIP report.

In 2003, the notion of an industry SXT Flight Mirror Assembly (FMA) Study was developed into a full and detailed study plan with much parallel discussion with industry. The plan was well received and the project was ready to implement it when a huge (about 50%) FY04 funding took place. The study by industry has been abandoned for the duration and the industry teams that had been assembled to compete for the study and hopefully carry it out have gone to work with a higher probability of sooner payoff. SAO put in a major effort in the planning for this study and in coordinating it with industry.